WILDE KRZYSZTOF

PASSIVE AERODYNAMIC CONTROL OF WIND INDUCED INSTABILITIES IN LONG SPAN BRIDGES

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CONTENTS

NOTATION

α, α_1, α_2	–	tosional displacement of bridge deck
a, b, c, d, e, f, l, m	–	variables defining geometry of wing-aileron-tab system
a_α, b_α, a_{hd}, b_{hd}, a_{vd}, b_{vd}, a_{hc}, b_{hc},	–	parameters for evaluation of damping
a_0, a_i (i = 1, ..., n_ℓ)	–	coefficients of approximation of Theodorsen’s function
a_h	–	distance between the center of rotation of the deck and the end of hanger cable
A_i (i = 1, ..., 4)	–	flutter derivatives of aerodynamic moment
$\mathbf{A}$	–	state space coefficient matrix
β	–	angular displacement of pendulum; torsional displacement of leading flap
b, b_1, b_2	–	half chord width of the bridge-flaps system, width of leading and trailing flap
b_c	–	half of the distance between main cables
b_i, $b_{i,i}$	–	lag coefficients of rational function approximation
B_d, B_1, B_2	–	width of the deck and control surface
c_1, c_2	–	control gains
c_h, c_α, c_β, c_γ	–	damping coefficients of heaving, pitching and flap motions
$C(s)$	–	Theodorsen’s function
C_D, C_L, C_M	–	drag, lift, moment steady force coefficient
C_{Dc}	–	steady drag coefficient of cable
$\mathbf{C}$	–	damping matrix
$\mathbf{C}_\mathrm{a}$	–	matrix of aerodynamic damping
$\mathbf{C}_{\mathrm{a},i}$ (i = 1,2)	–	matrix of aerodynamic damping of leading and trailing surface
$\mathbf{C}^e_a$	–	element aerodynamic damping matrix
$\mathbf{C}_\mathbf{s}$	–	matrix of structural damping
$\mathbf{C}^e_{sh_d}, \mathbf{C}^e_{sv_d}, \mathbf{C}^e_{s\alpha}, \mathbf{C}^e_{sh_c}$	–	damping matrices corresponding to horizontal, vertical, torsional displacement of the deck and motion of main cables
d, d_1, d_2	–	places of connection of surfaces to the pendulum
d_c	–	diameter of main cables
$D(C(k), \tilde{C}(k))$	–	distance between points of curves $C(k)$ and $\tilde{C}(k)$
D_c	–	drag force on main cable
D_d, D_1, D_2	–	drag force on bridge deck and control surfaces
D_r, L_r, M_r	–	relative drag, lift and moment force
$\mathbf{D}$	–	matrix of rational function approximation of deck forces
$\mathbf{D}_{1,i}$ (i = 1,2)	–	matrix of rational function approximation of surfaces forces
$\mathbf{D}^e_{sec}$, $\mathbf{D}^e$	–	global coefficient matrices of rational function approximation
ε	–	approximation error
$\mathbf{E}$	–	matrix of rational function approximation
e_1, e_2	–	position of hinge lines of control surfaces with respect to the center of the bridge deck
e_{c1}, e_{c2}	–	location of the hinges of flaps with respect to the center of gravity of the bridge deck

$\mathbf{E}_{1,i}$ (i = 1,2)	–	matrix of rational function approximation of surfaces forces
$\mathbf{E}_a$, $\mathbf{R}_b$, $\mathbf{E}_b$	–	global matrices of coefficients of rational function approximation
$\mathbf{E}^e{}_a$, $\mathbf{R}^e{}_b$, $\mathbf{E}^e{}_b$	–	matrices of coefficients of rational function approximation for finite element of aerodynamic forces
ϕ	–	relative angle of attack
ϕ_h , ϕ_α	–	phases of heaving and pitching motion
φ_{h1}, φ_{h2}	–	inclination angles of hanger cables
ϕ_{Lexp}, ϕ_{Mexp}	–	phases of experimentally obtained aerodynamic lift and moment
F	–	dissipation function
$\mathbf{F}$	–	total aerodynamic forces acting on the bridge deck
$\mathbf{F}_d$, $\mathbf{F}_1$, $\mathbf{F}_2$	–	vector aerodynamic forces on deck and control surfaces
$\mathbf{F}_\mathrm{s}$	–	vector of static aerodynamic forces
γ	–	torsional displacement of trailing flap
h, h_1, h_2	–	vertical displacement of bridge deck and leading and trailing surfaces
h_0, α_0, β_0	–	amplitudes of excitation of heaving, pitching and rotation of leading flap
h_d, h_{c1}, h_{c2}	–	horizontal displacement of deck and main cables
H	–	depth of bridge deck; tension force in main cables
ΔH, ΔH_i (i = 1, 2, 3)	–	increment in horizontal tension forces
H_i (i = 1, ..., 4)	–	flutter derivatives of lift force
$H_n^{(2)}$ (i = 1,2)	–	Henkel functions
I	–	mass moment of inertia
$\boldsymbol{I}$	–	identity matrix
χ	–	inclination of cable element
k_h, k_α, k_β, k_γ	–	stiffness coefficients of heaving, pitching and flap motions
k_{low}, k_{up}	–	lower and upper bound for approximation of Theodorsen's function
K, k	–	reduced frequency
$\mathbf{K}_\mathrm{a}$	–	matrix of aerodynamic stiffness
$\mathbf{K}_{\mathrm{a},i}$ (i = 1,2)	–	matrices of aerodynamic stiffness of leading and trailing surface
$\mathbf{K}^e{}_a$	–	element aerodynamic stiffness matrix
$\mathbf{K}_b$, $\mathbf{K}_{cc}$,	–	stiffness matrices due to supporting system
$\mathbf{K}^e{}_{sh}$	–	cable element structural stiffness matrix due to geometric stiffness of hanger cables
$\mathbf{K}^e{}_{sd}$	–	element structural stiffness matrix
$\overline{\mathbf{K}}{}^e_{sc}$	–	cable element gravity stiffness matrix
$\mathbf{K}_\mathbf{s}$	–	matrix of structural stiffness
$\mathbf{K}_{sup}$	–	stiffness matrix due to supporting beam
λ_i	–	eigenvalues
$\mathbf{L}$	–	ordinary matrix differential operator
L $\tilde{L}_i$ $(i=1,\ 2,\ 3)$	–	length of cable of i-th span
L_{0exp}, M_{0exp}	–	amplitudes of experimentally obtained aerodynamic lift and moment
L_{0th}, M_{0th}	–	amplitudes of lift and moment determined theoretically
L_d, L_1, L_2	–	lift force on bridge deck and control surfaces

L_{exp}, M_{exp}	–	experimentally obtained aerodynamic lift and moment
l_h	–	length of hanger cable
L_h, M_α, M_β, M_γ	–	lift and moment forces acting of bridge-flaps system
L_i (i = 1, 2, 3)	–	lengths of side and main spans
L_ℓ, U_ℓ	–	lower and upper constrains for optimization of lag coefficients
$\mathbf{M}$	–	mass matrix
m	–	mass per unit length
$M_{\beta 0}$, $M_{\gamma 0}$	–	prestressing moments of control cables
M_d, M_1, M_2	–	lift force on bridge deck and control surfaces
$\mathbf{M}^e{}_a$	–	element aerodynamic mass matrix
$\mathbf{M}^e{}_s$	–	element structural mass matrix
M_{ij}, w_{ij}	–	weighting factor of approximation function
$\mathbf{M}_s$	–	matrix of structural mass
$\mathbf{N}$	–	shape function matrix of structural element
$\mathbf{N}_a$	–	shape function matrix for aerodynamic states
n_ℓ	–	number of lag coefficients
$\tilde{\mathbf{N}}^e_{c1}$, $\tilde{\mathbf{N}}^e_{c2}$	–	shape function matrices for cable elements
p	–	dimensionless Laplace variable
$\mathbf{P}$	–	vector of wing-aileron-tab system
P_i (i = 1, ..., 4)	–	flutter derivatives of drag force
ρ	–	air density
$\mathbf{Q}$	–	matrix of coefficients of unsteady aerodynamic forces
$\mathbf{q}$	–	independent degrees of freedom of deck surfaces system
$\mathbf{q}_1$, $\mathbf{q}_2$	–	vectors of absolute displacements of leading and trailing surfaces
$\mathbf{q}_d$	–	vector of deck's displacements
q^e	–	vector of element structural degrees of freedom
$\mathbf{q}^e{}_a$	–	vector of nodal aerodynamic states of finite element
q_f	–	vector of relative displacements of flaps
q_h, q_α, q_β, q_γ	–	displacements of wind-aileron-tab system
$\mathbf{q}_t$	–	vector of displacements of wind-aileron-tab system
$\mathbf{R}$	–	matrix of lag coefficients; matrix of geometry of wind-aileron-tab combination
r	–	global dispalcement vector structural degrees of freedom
s	–	Laplace variable
S_α, S_β, S_γ	–	first moment of inertia of the deck, leading flap and trailing flap
$\mathbf{S}_1$, $\mathbf{S}_2$	–	coordinate transformation matrices; matrices of geometry of wind-aileron-tab system
$\mathbf{S}_d$	–	coordinate transformation matrix
t	–	time
$\mathbf{T}$, $\mathbf{T}_q$	–	coordinate transformation matrix
$T^e{}_d$, $T^e{}_{c1}$, $T^e{}_{c2}$	–	kinetic energy of structural finite element due to deck and main cables
T_p	–	period of pendulum
U	–	mean wind speed
u_c, h_c, v_c,	–	longitudinal, horizontal and vertical displacement of the cable
U_d	–	divergence wind speed

U_f	–	flutter wind speed
U_r	–	relative wind speed
$\mathbf{V}$, $\mathbf{V}_1$, $\mathbf{V}_2$	–	matrices of dynamic pressure
V_c	–	potential energy of cables
$\bar{V}$	–	potential energy of cables arising from gravity
$\tilde{V}_c$	–	strain potential energy of cables
$V^e{}_h$	–	cable element potential energy due to stiffness properties of hanger cables
v_d, v_{c1}, v_{c2}	–	vertical displacement of deck and main cables
$V^e{}_d$, $V^e{}_{c1}$, $V^e{}_{c2}$	–	potential energy of structural finite element due to deck and main cables
$v_{\boldsymbol{i}}$	–	eigenvectors
ω	–	circular frequency of oscillation
x	–	horizontal displacement of bridge deck
$\mathbf{X}$	–	vector of global nodal forces
$\boldsymbol{x}_a$	–	vector of aerodynamic states
x_{c1}, x_{c2}	–	points of connection of control cables to the supporting beam
$\mathbf{x}^{\mathrm{e}}$	–	displacement vector of element cross-section
$\mathbf{x}^e{}_a$	–	vector of aerodynamic states of section of bridge deck
$\mathbf{X}^{\mathrm{e}}{}_{\mathrm{sec}}$	–	vector of forces of element cross-section
$\mathbf{X}^e{}_U$	–	vector of displacement independent static wind forces
ξ	–	damping ratio
y	–	cable deflection